Tissue Ablating Apparatus and Method of Ablating Tissue

BACKGROUND TO THE INVENTION

FIELD OF THE INVENTION

The present invention relates to an apparatus and method for ablating tissue with microwave radiation. In this specification microwave means the frequency range from 5GHz to 60GHz inclusive. Preferably 14-15GHz is used for tissue ablation but the present invention is not limited to this narrower range.

SUMMARY OF THE PRIOR ART

Traditional methods of treating cancer involve removing the cancerous tissue by cutting it out mechanically and/or chemotherapy, usually followed by radiotherapy. Both methods have significant drawbacks and may cause serious trauma to the patient.

The application of heat energy to biological tissue is an effective method of killing cells. Thus the present invention proposes applying microwaves to heat and thus ablate (destroy) biological tissue. This presents an interesting opportunity for the treatment of cancer as the cancerous tissue can be ablated in this way. There is a need for a suitable apparatus and method for ablating tissue with microwaves for the treatment of cancer or other conditions.

SUMMARY OF THE INVENTION

Accordingly a first aspect of the present invention may provide a tissue ablation apparatus comprising:

a source of microwave radiation;

the direction of the axis of said probe of $\lambda/4$ or odd multiples thereof.

31. A method of making a balun for a coaxial tissue ablation probe comprising the steps of spraying or otherwise placing a liquid or powder dielectric onto an outer surface of an outer conducting sheath of a coaxial probe, and if said dielectric is liquid allowing the liquid to solidify, to form the balun.

32. A method according to claim 31 comprising the further step of and placing an outer conductor around said dielectric.

33. A method according to claim 32 wherein said probe is designed for use with a microwave radiation of wavelength λ and the balun has a length in the direction of the axis of said probe of $\lambda/4$ or odd multiples thereof.

34. A surgical apparatus comprising:

a source of microwave radiation of a first frequency suitable for ablating tissue;

a probe for directing microwave radiation from the source into tissue to be ablated;

a modulator having an OFF state in which it does not modulate said microwave radiation from the source and an ON state in which it modulates microwave radiation from the source in pulses having a second frequency less than said first frequency; said second frequency being suitable for cutting tissue.

35. An apparatus according to claim 29 wherein the apparatus further comprises a low pass filter between said modulator and said probe; said low pass filter having a first state in which it lets said first frequency pass and a second state in which it passes said second frequency, but filters out said first frequency.

36. An apparatus according to claim 34 wherein said modulator is capable of varying said second frequency.

37. An apparatus according to claim 36 wherein said modulator is capable of varying said second frequency and said low pass filter is capable of varying its pass band in its second state.

38. An apparatus according to any one of claims 34 to 37 wherein said first frequency is 5GHz or higher.

39. An apparatus according to any one of claim 34 to 38 wherein said second frequency is a frequency in the range 10kHz to 500MHz.

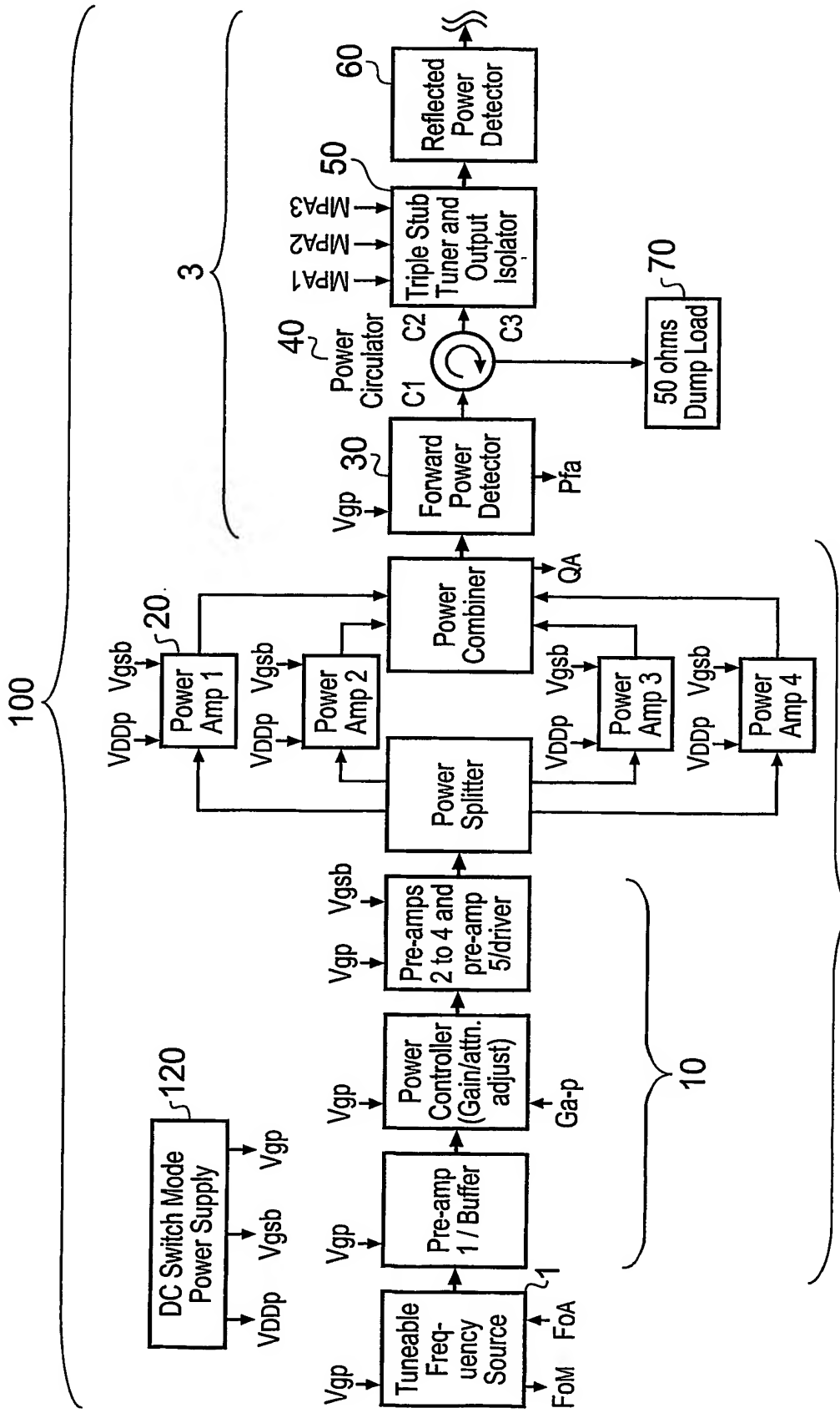


Fig. 1 (continued on page 2/14)

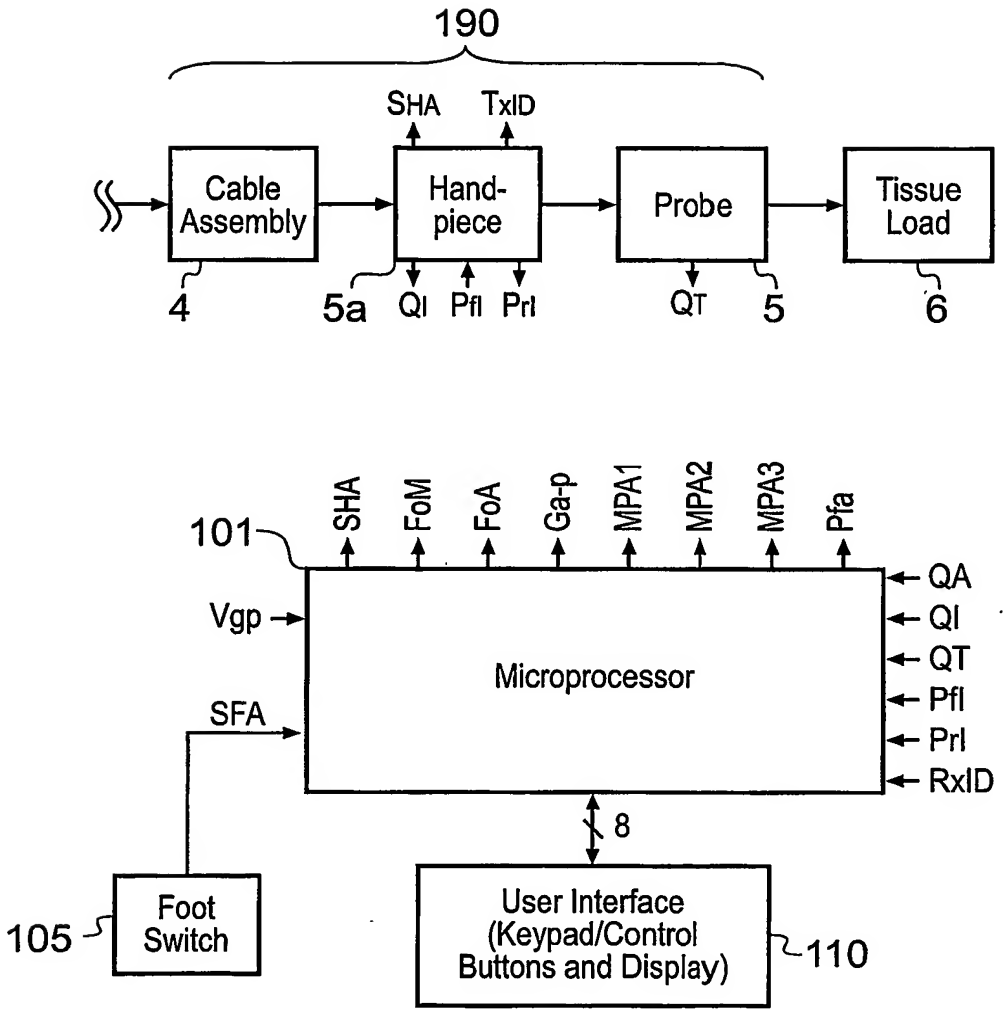


Fig. 1 (continued from page 1/14)

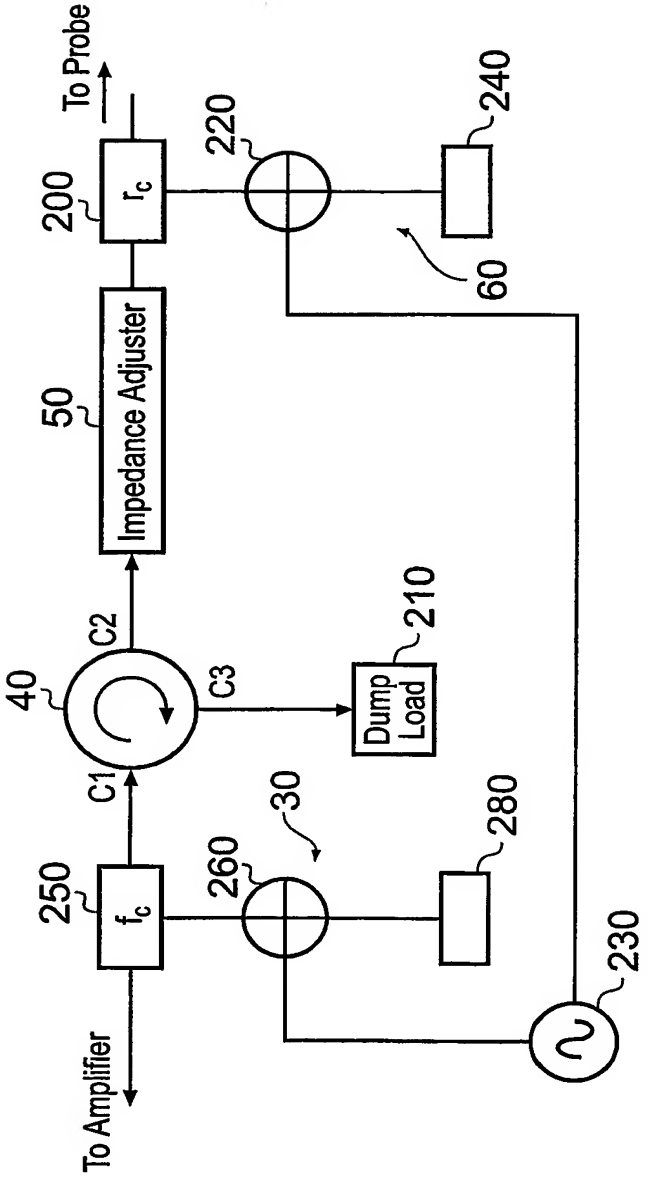

To Probe
200
r_c
220
240
60
50
Impedance Adjuster
C2
210
40
C3
Dump Load
C1
30
280
250
f_c
260
230
To Amplifier

Fig. 2

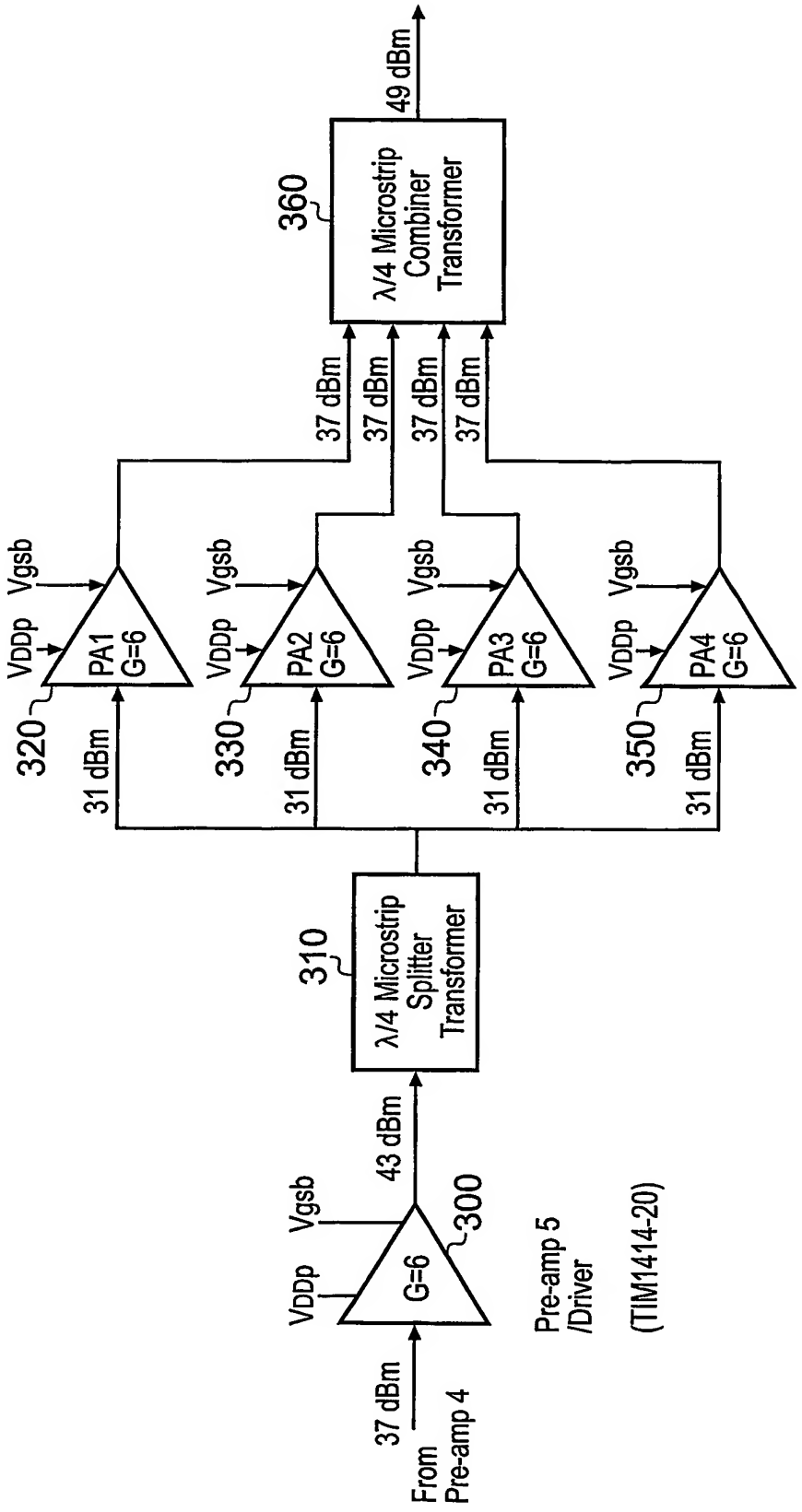

From Pre-amp 4
37 dBm
VDDp
Vgsb
G=6
300
Pre-amp 5 /Driver (TIM1414-20)
43 dBm
λ/4 Microstrip Splitter Transformer
310
31 dBm
320
PA1 G=6
330
PA2 G=6
340
PA3 G=6
350
PA4 G=6
37 dBm
λ/4 Microstrip Combiner Transformer
360
49 dBm

Fig. 3

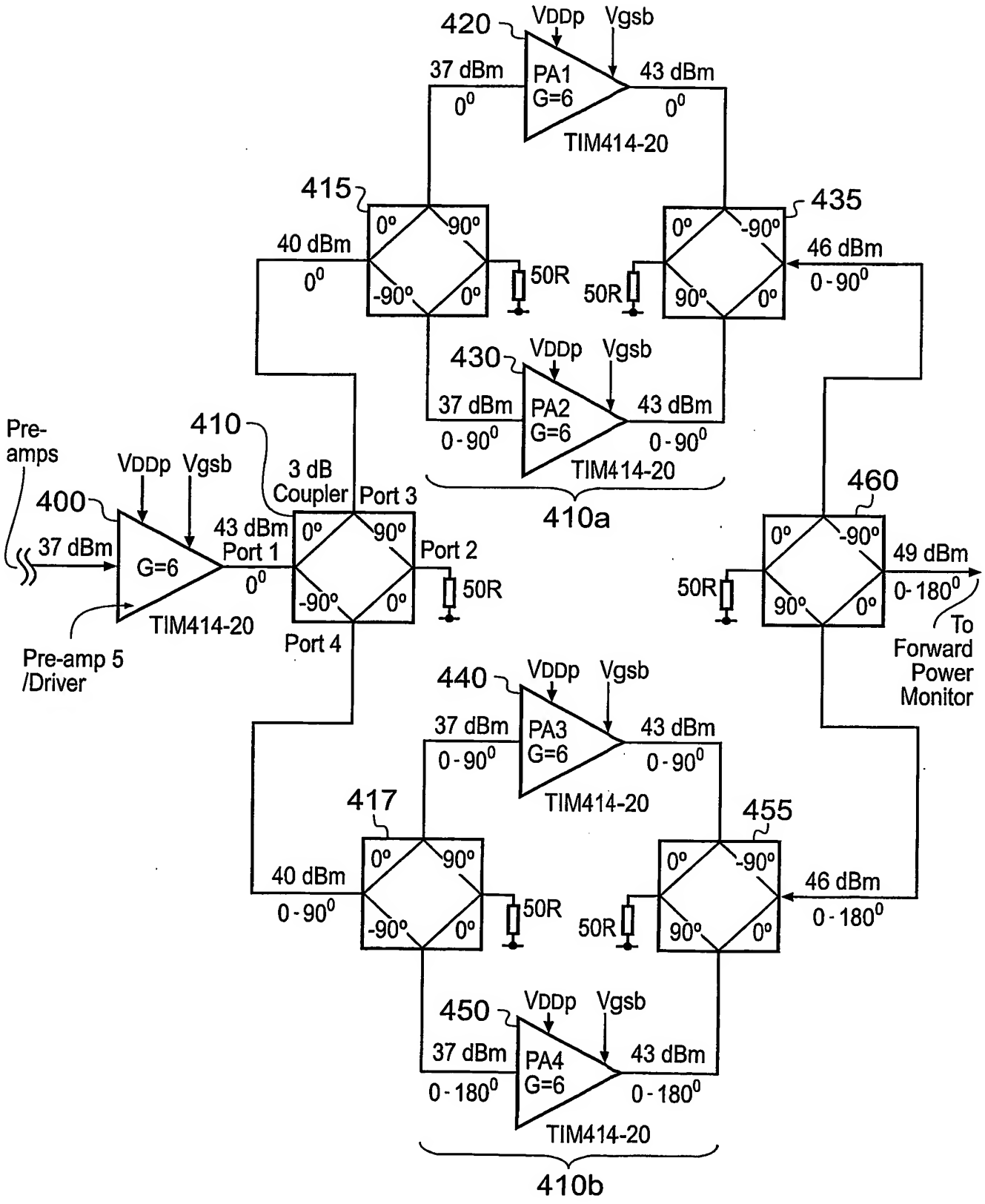

420
VDDp
Vgsb
37 dBm
PA1
G=6
43 dBm
0°
0°
TIM414-20
415
435
40 dBm
0°
0°
90°
-90°
0°
50R
50R
0°
-90°
90°
0°
46 dBm
0-90°
430
VDDp
Vgsb
37 dBm
PA2
G=6
43 dBm
0-90°
0-90°
TIM414-20
410a
Pre-
amps
410
400
VDDp
Vgsb
3 dB
Coupler
Port 3
37 dBm
G=6
43 dBm
Port 1
0°
0°
90°
Port 2
50R
-90°
0°
TIM414-20
Port 4
Pre-amp 5
/Driver
460
0°
-90°
49 dBm
50R
0-180°
90°
0°
To
Forward
Power
Monitor
440
VDDp
Vgsb
37 dBm
PA3
G=6
43 dBm
0-90°
0-90°
TIM414-20
417
455
40 dBm
0-90°
0°
90°
-90°
0°
50R
50R
0°
-90°
90°
0°
46 dBm
0-180°
450
VDDp
Vgsb
37 dBm
PA4
G=6
43 dBm
0-180°
0-180°
TIM414-20
410b

Fig. 4

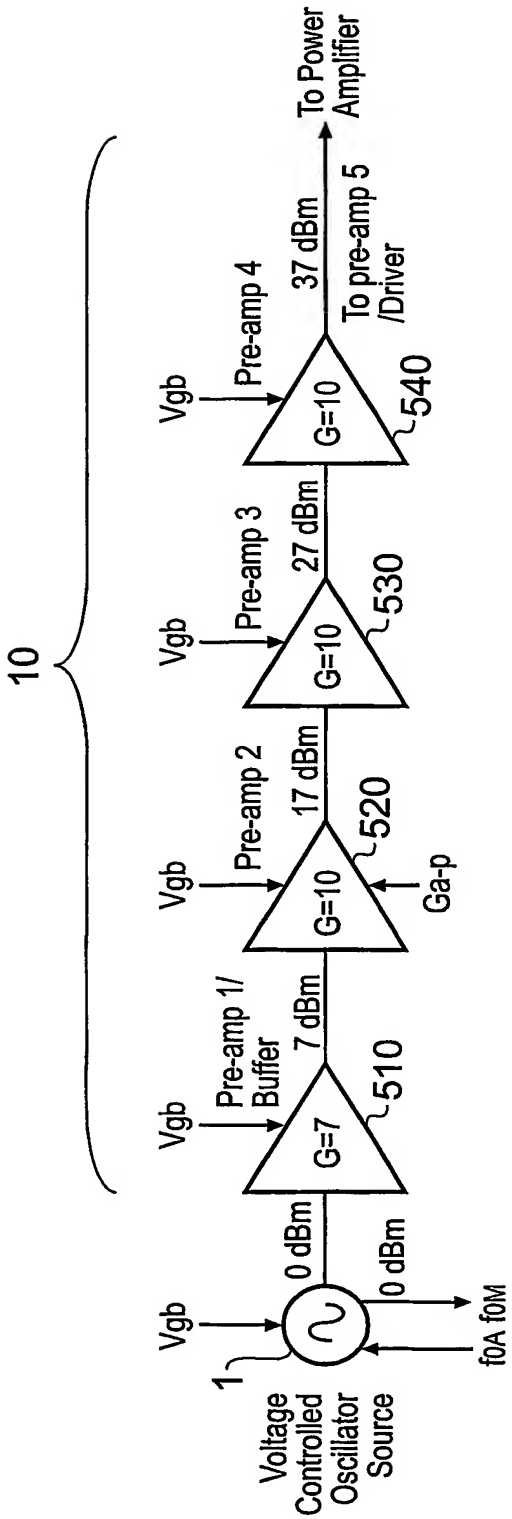

10
Vgb
Voltage Controlled Oscillator Source
1
0 dBm
f0A f0M
0 dBm
Vgb
Pre-amp 1/ Buffer
G=7
510
7 dBm
Vgb
Pre-amp 2
G=10
520
Ga-p
17 dBm
Vgb
Pre-amp 3
G=10
530
27 dBm
Vgb
Pre-amp 4
G=10
540
37 dBm
To pre-amp 5 /Driver
To Power Amplifier

Fig. 5

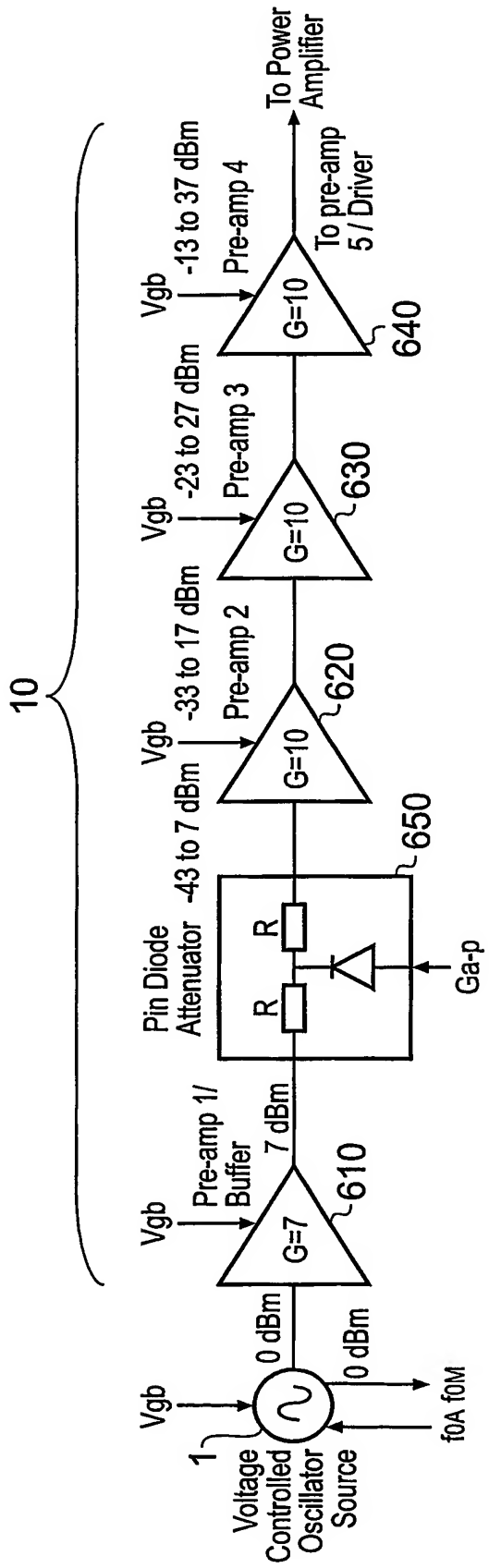

10
1
Voltage Controlled Oscillator Source
Vgb
0 dBm
f0A f0M
0 dBm
Vgb
Pre-amp 1/ Buffer
G=7
610
7 dBm
Pin Diode Attenuator
-43 to 7 dBm
R
R
Ga-p
650
Vgb
-33 to 17 dBm
Pre-amp 2
G=10
620
Vgb
-23 to 27 dBm
Pre-amp 3
G=10
630
Vgb
-13 to 37 dBm
Pre-amp 4
G=10
640
To pre-amp 5 / Driver
To Power Amplifier

Fig. 6

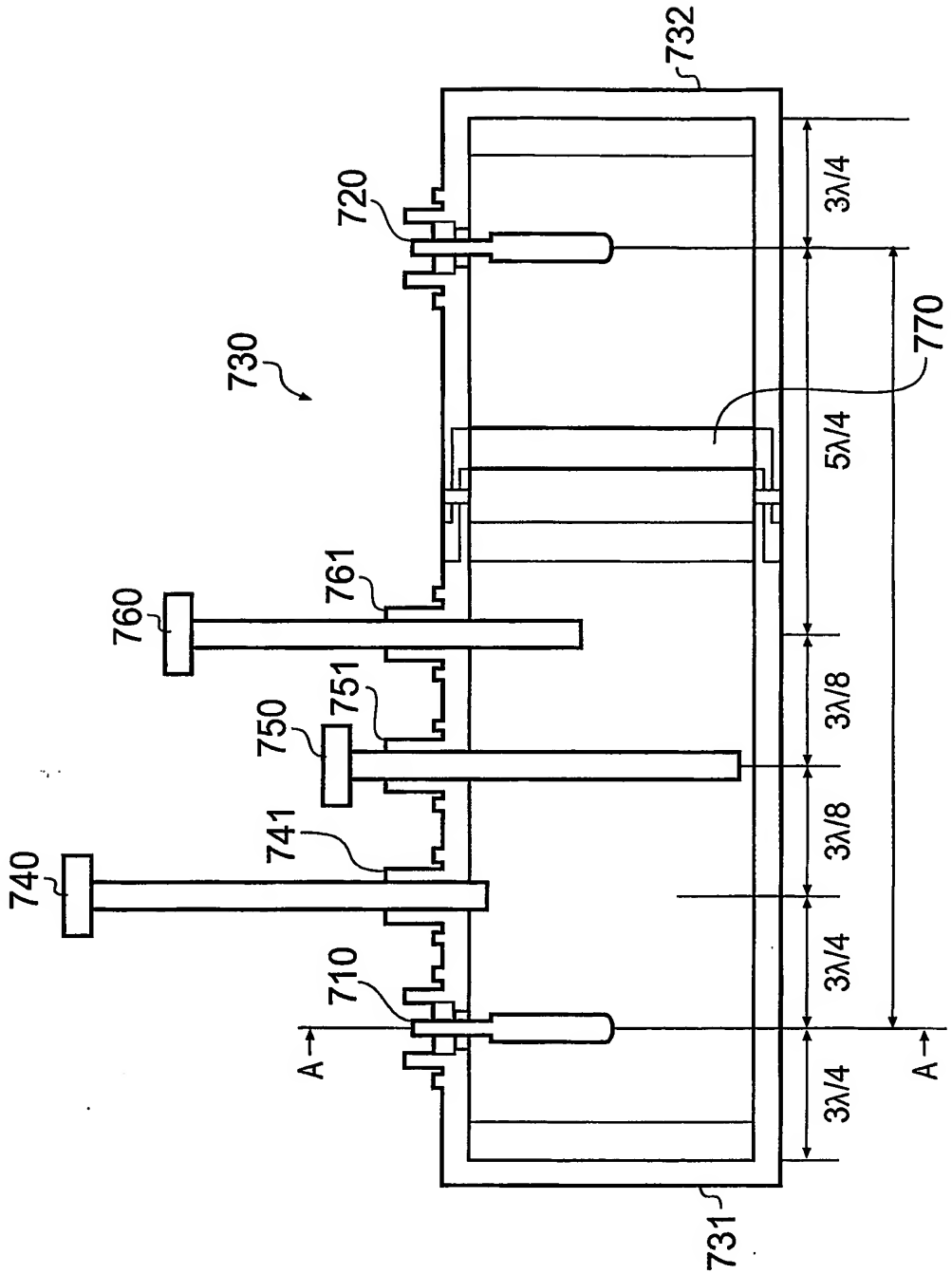

732
720
730
770
761
760
751
750
741
740
710
731
A
A
3λ/4
5λ/4
3λ/8
3λ/8
3λ/4
3λ/4

Fig. 7

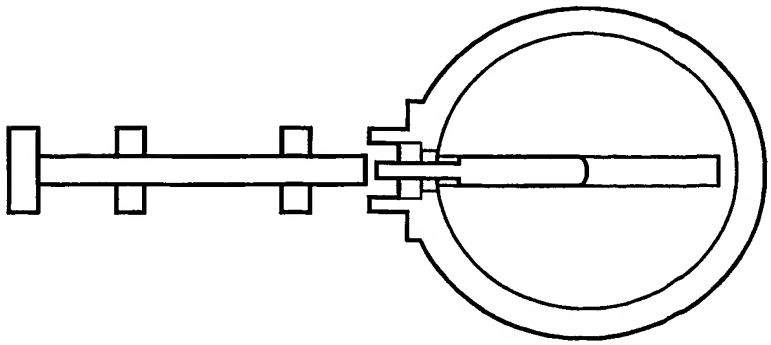

Section A - A

Fig. 8

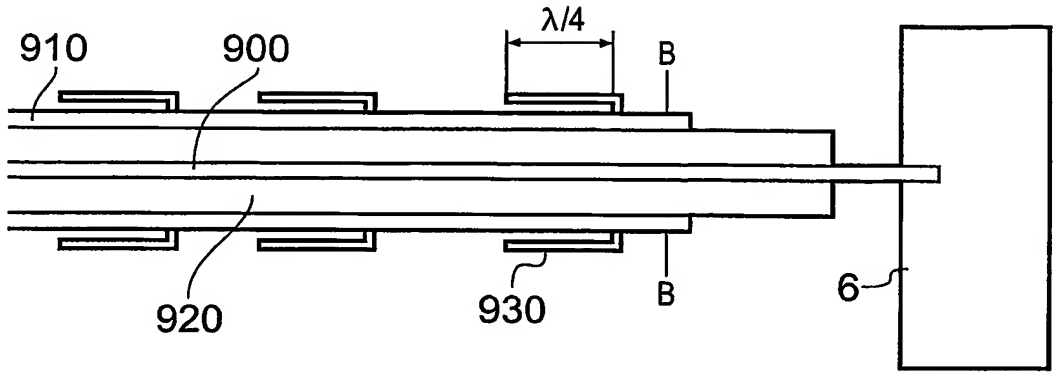


Fig. 9

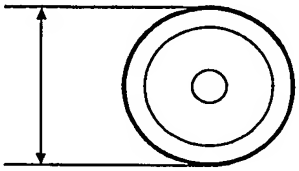


Fig. 10

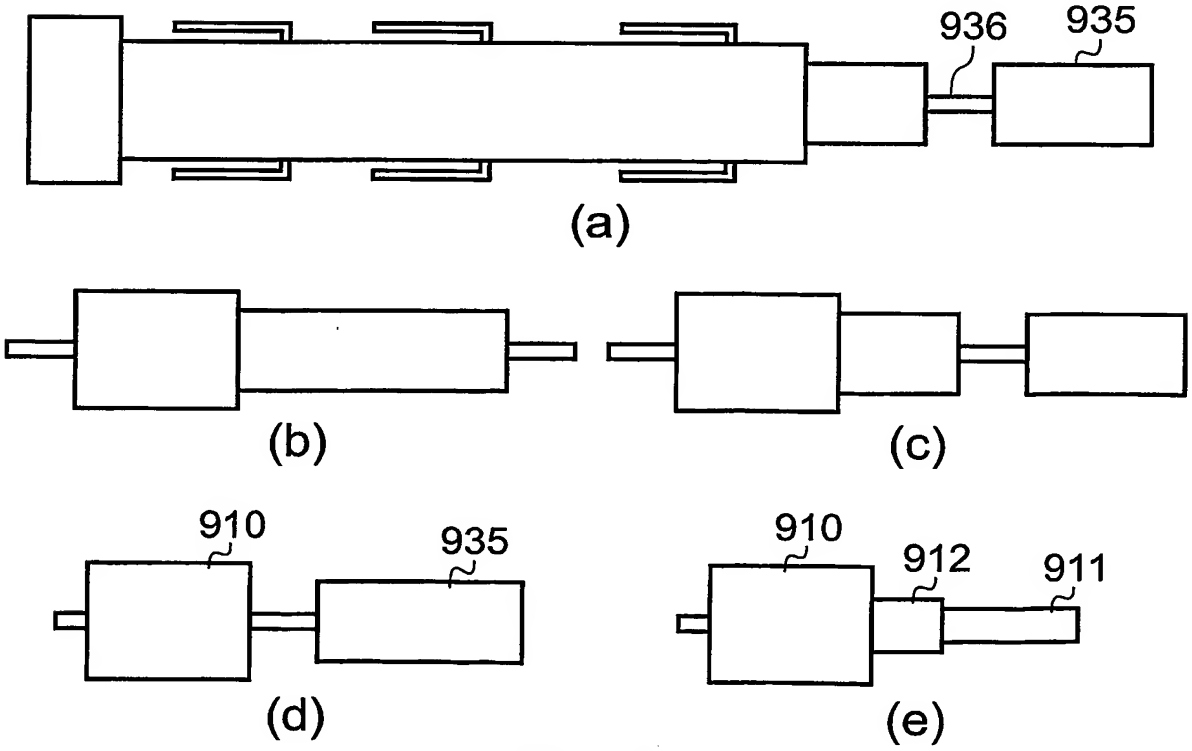


Fig. 11

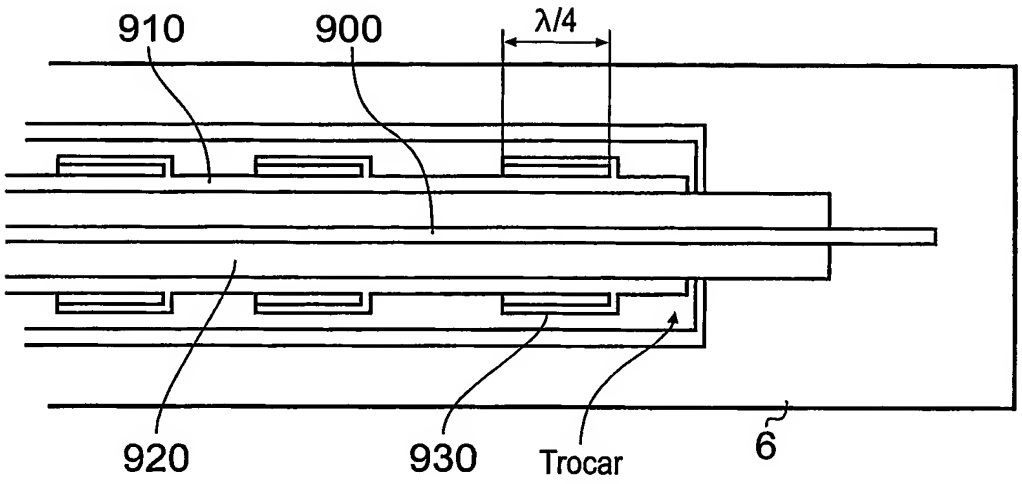
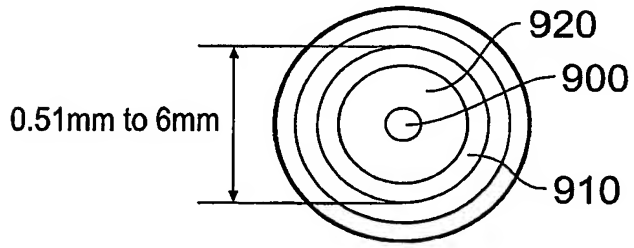


Fig. 12



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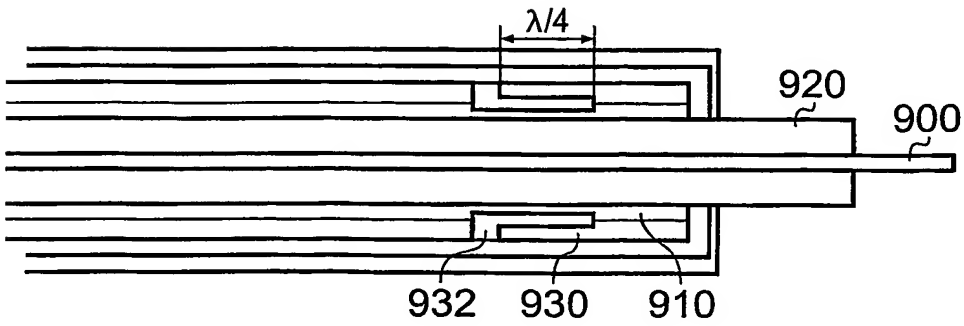


Fig. 14

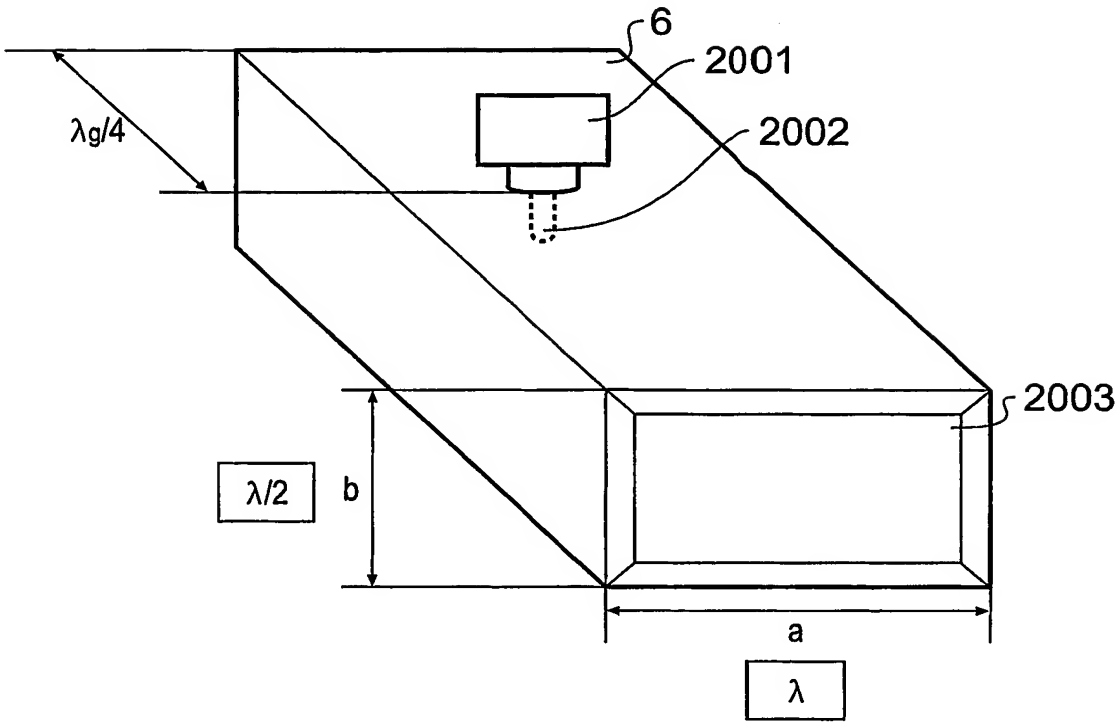
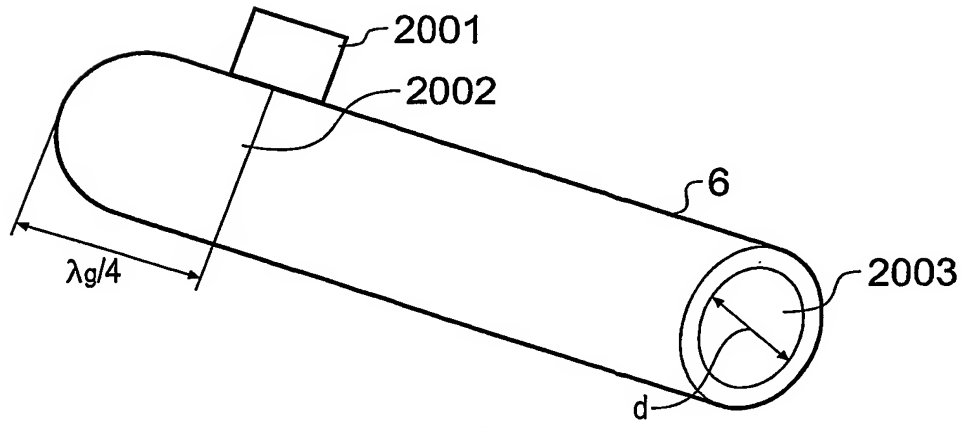


Fig. 15



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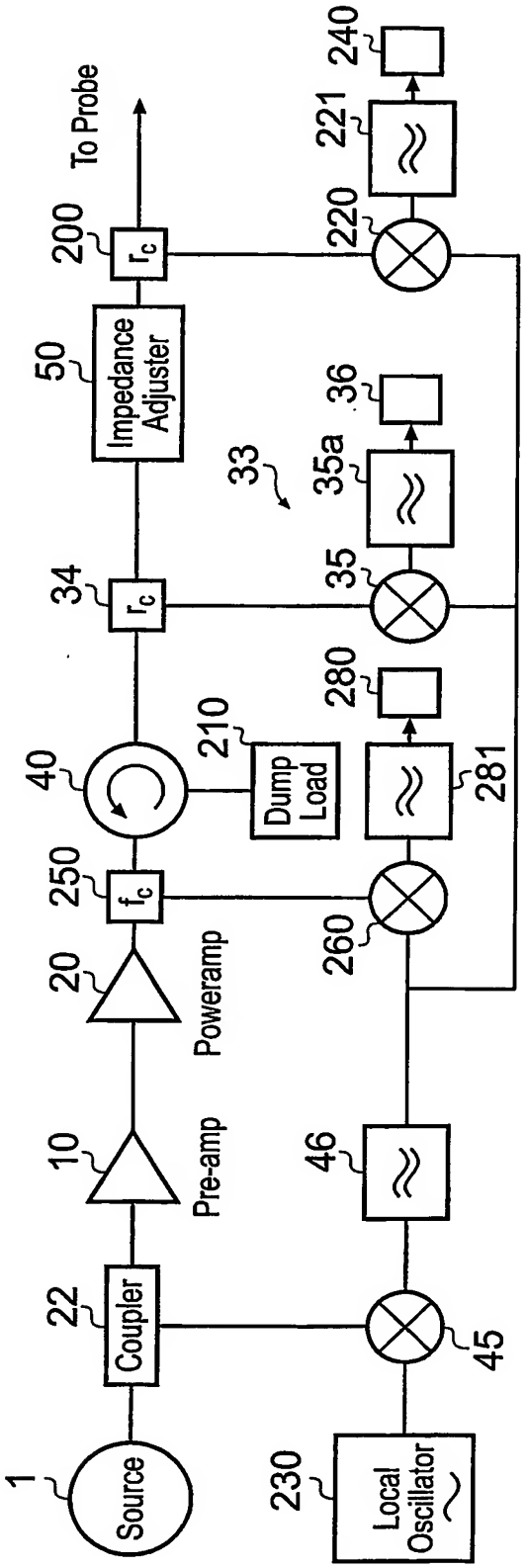
To Probe
200
r_c
50
Impedance Adjuster
34
r_c
40
210
Dump Load
250
f_c
20
Poweramp
10
Pre-amp
22
Coupler
1
Source
230
Local Oscillator
45
46
260
280
281
35
35a
33
36
220
221
240

Fig. 16

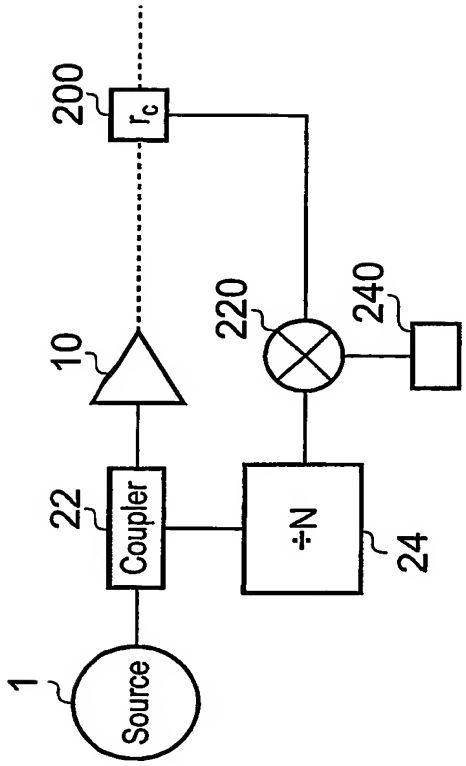
200
r_c
10
22
Coupler
1
Source
÷N
24
220
240

Fig. 17

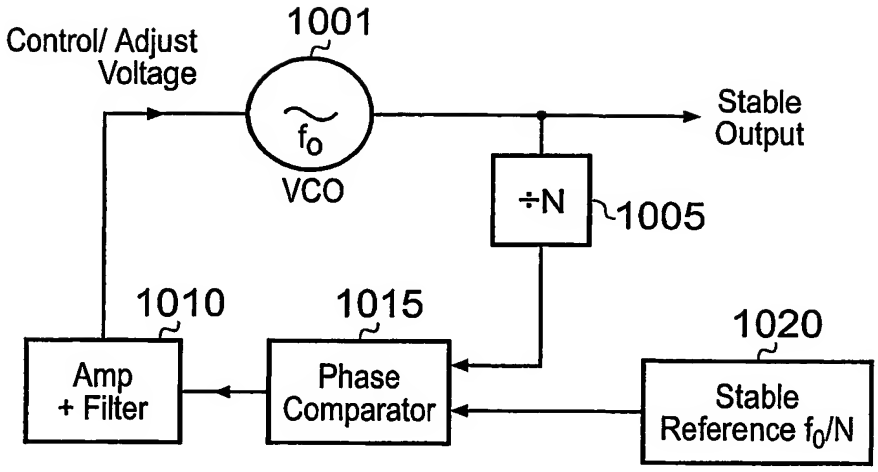

Fig. 19

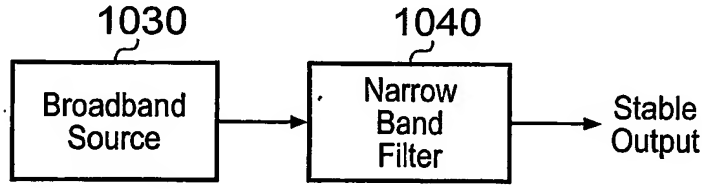

Fig. 20

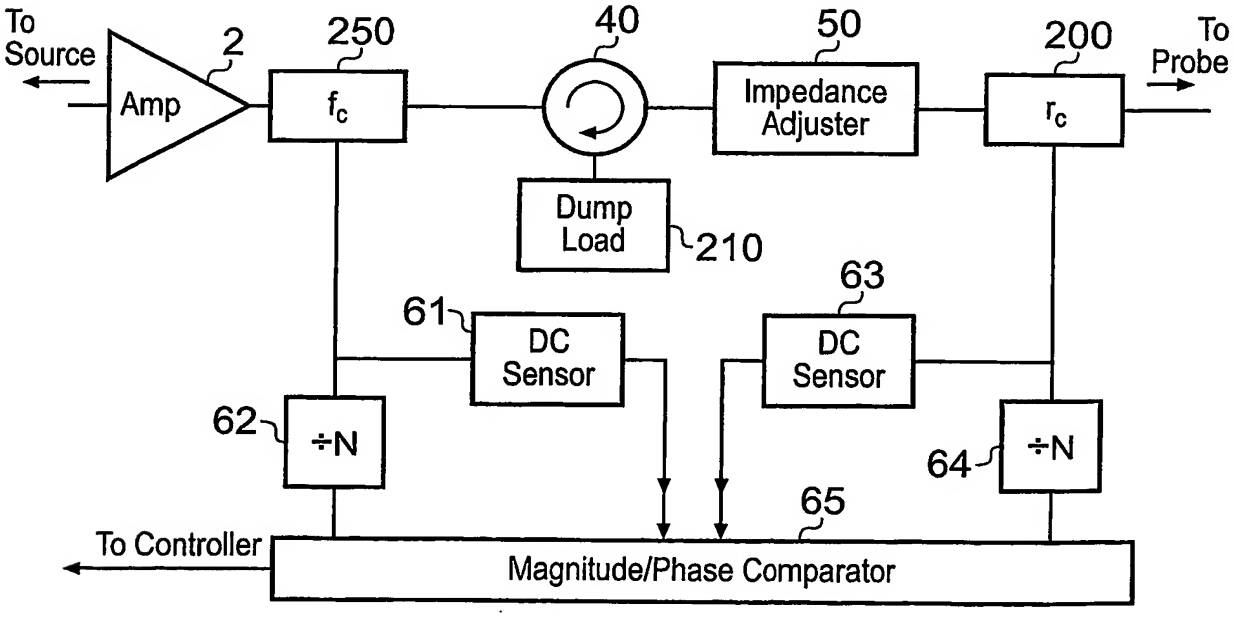

Fig. 18

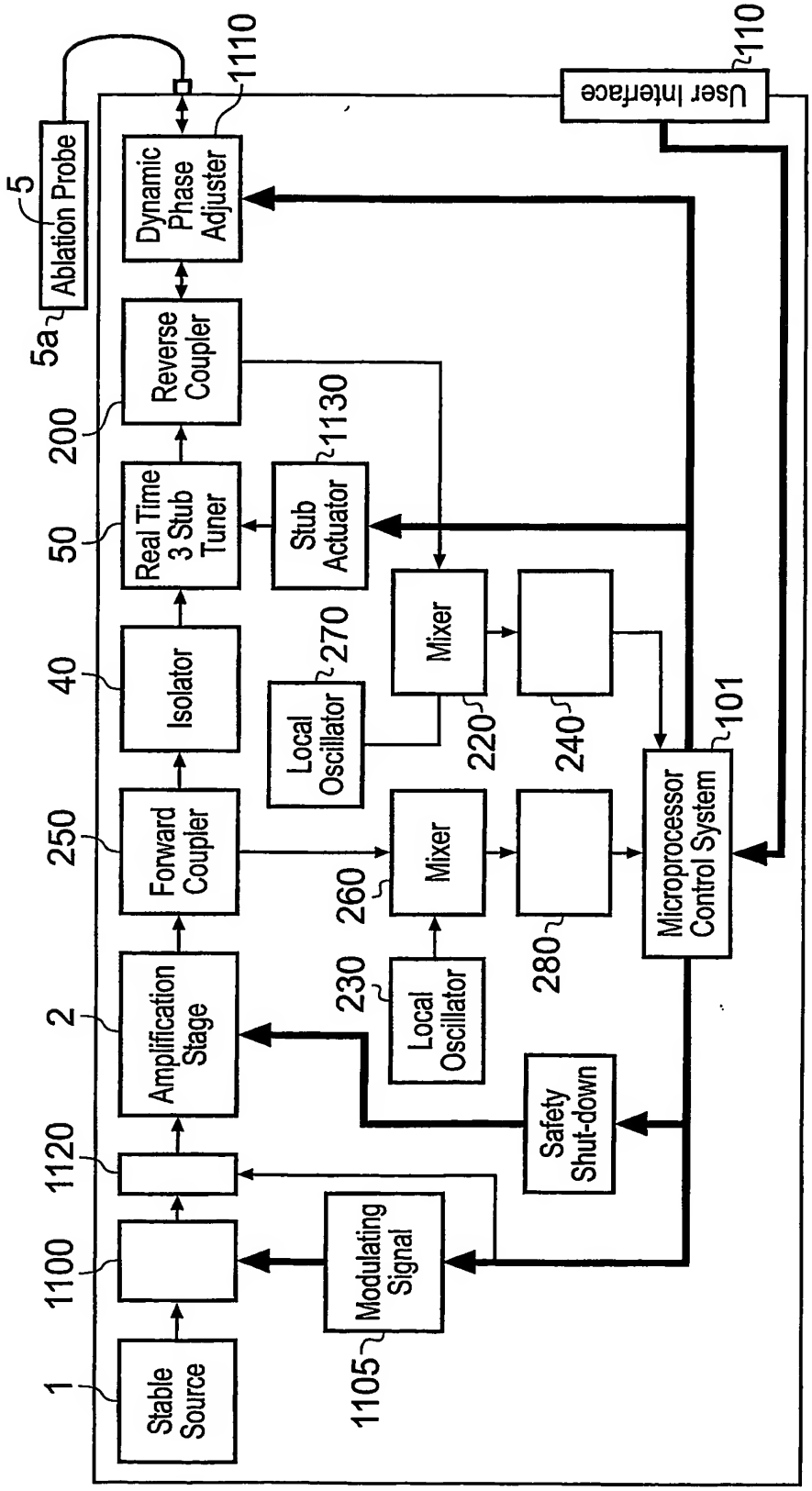
User Interface
110
1110
Dynamic Phase Adjuster
5
Ablation Probe
5a
Reverse Coupler
200
Real Time 3 Stub Tuner
50
Stub Actuator
1130
Isolator
40
Local Oscillator
270
Mixer
220
240
Forward Coupler
250
Mixer
260
Microprocessor Control System
101
Amplification Stage
2
Local Oscillator
230
280
1120
Safety Shut-down
1100
Modulating Signal
1105
1
Stable Source

Fig. 21

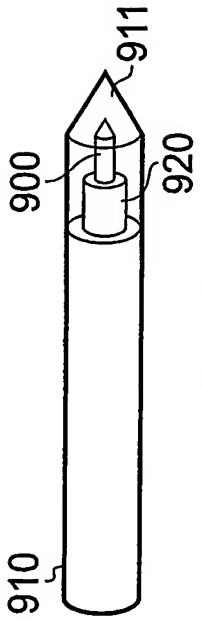
911
900
920
910

Fig. 23

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(19) World Intellectual Property Organization
International Bureau

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10 June 2004 (10.06.2004)

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(74) Agents: **CALDERBANK, T., Roger** et al.; Mewburn Ellis, York House, 23 Kingsway, London, Greater London WC2B 6HP (GB).

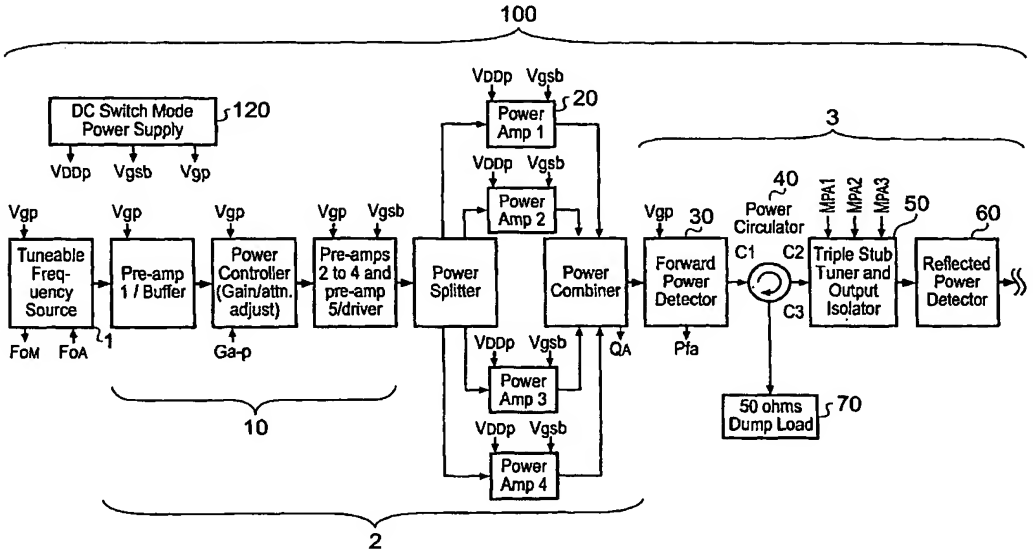
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(regional)*: ARIPO patent (BW, GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

[Continued on next page]

(54) **Title:** TISSUE ABLATION APPARATUS AND METHOD OF ABLATING TISSUE



(57) **Abstract:** An apparatus and method for ablating tissue is disclosed. The apparatus comprises a source of microwave radiation (1), a probe (5) for directing the microwave radiation into tissue, one or more detectors for detecting the power and phase of the microwave radiation and an impedance adjuster (50) for adjusting impedance so as to minimize the amount of microwave radiation which reflected back through the probe. The detector or detectors use a local oscillator (230) to derive the phase information. A modulator for modulating the microwave radiation to a cutting frequency is also disclosed.

WO 2004/047659 A3

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

(88) Date of publication of the international search report:
29 July 2004

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

INTERNATIONAL SEARCH REPORT

Application No
PCT/GB 03/05166

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 A61B18/14

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 957 969 A (GRUNDY DAVID ALAN ET AL) 28 September 1999 (1999-09-28) column 2, line 11 -column 15, line 3; figures 1,6-12	1-18
X	US 5 693 082 A (GRUNDY DAVID ALAN ET AL) 2 December 1997 (1997-12-02) column 2, line 7 -column 14, line 67; figures 1,6-12	1-18
X	US 5 364 392 A (WARNER GLEN G ET AL) 15 November 1994 (1994-11-15) column 2, line 30 -column 8, line 40; figures 1,6,7	1-18

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 May 2004	11. 06. 2004

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Kurze, V

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INTERNATIONAL SEARCH REPORT

Application No
PCT/GB 03/05166

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 405 346 A (WARNER GLEN G ET AL) 11 April 1995 (1995-04-11) column 3, line 14 -column 12, line 31; figures 2-4,8,9	1-18
X	EP 1 186 274 A (AFX INC) 13 March 2002 (2002-03-13) column 1, line 41 -column 36, line 27; figure 2	1-18
X A	US 6 413 255 B1 (STERN ROGER A) 2 July 2002 (2002-07-02) column 3, line 60 -column 30, line 10	34,36, 38,39 37
X A	WO 00/53113 A (STERN ROGER ;THERMAGE INC (US)) 14 September 2000 (2000-09-14) page 9, line 8 -page 48, line 14	34,36, 38,39 37
X A	US 2002/120261 A1 (MORRIS DAVID L ET AL) 29 August 2002 (2002-08-29) paragraph '0008! - paragraph '0193!; figure 55	34,36, 38,39 37
A	US 6 350 276 B1 (KNOWLTON EDWARD W) 26 February 2002 (2002-02-26) column 2, line 20 -column 22, line 32; figures 23-25	34,36-39
A	WO 97/43971 A (SOMNUS MEDICAL TECH INC ;EDWARDS STUART D (US)) 27 November 1997 (1997-11-27) page 4, line 2 -page 31, line 21	34,36-39

INTERNATIONAL SEARCH REPORT

application No.
PCT/GB 03/05166

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.: 19-26
because they relate to subject matter not required to be searched by this Authority, namely:

Rule 39.1(iv) PCT - Method for treatment of the human or animal body by surgery

2. [ ] Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. [ ] As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. [X] As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

1-18,34,36-39

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest.

[X] No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. Claims: 1-18

   Tunable tissue ablation apparatus

2. Claim : 27

   Probe with ceramic tip

3. Claims: 28-33,35,38,39

   Coaxial probe and method of making a balun therefor

4. Claims: 34,36-39

   Surgical apparatus with modulator

INTERNATIONAL SEARCH REPORT

Information on patent family members

Application No
PCT/GB 03/05166

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5957969 A	28-09-1999	US 5693082 A	02-12-1997
		US 5364392 A	15-11-1994
		US 5405346 A	11-04-1995
		AU 6912794 A	12-12-1994
		EP 0697842 A1	28-02-1996
		WO 9426188 A1	24-11-1994
US 5693082 A	02-12-1997	US 5364392 A	15-11-1994
		US 5405346 A	11-04-1995
		US 5957969 A	28-09-1999
		AU 6912794 A	12-12-1994
		EP 0697842 A1	28-02-1996
		WO 9426188 A1	24-11-1994
US 5364392 A	15-11-1994	AU 6912794 A	12-12-1994
		EP 0697842 A1	28-02-1996
		WO 9426188 A1	24-11-1994
		US 5405346 A	11-04-1995
		US 5693082 A	02-12-1997
		US 5957969 A	28-09-1999
US 5405346 A	11-04-1995	US 5364392 A	15-11-1994
		AU 6912794 A	12-12-1994
		EP 0697842 A1	28-02-1996
		WO 9426188 A1	24-11-1994
		US 5693082 A	02-12-1997
		US 5957969 A	28-09-1999
EP 1186274 A	13-03-2002	EP 1186274 A2	13-03-2002
US 6413255 B1	02-07-2002	US 2002151887 A1	17-10-2002
		US 2002156471 A1	24-10-2002
		US 2003216728 A1	20-11-2003
		US 2004034346 A1	19-02-2004
		US 2003199866 A1	23-10-2003
		US 2004002704 A1	01-01-2004
		US 2004000316 A1	01-01-2004
		US 2003212393 A1	13-11-2003
		US 2004030332 A1	12-02-2004
		US 2004002705 A1	01-01-2004
		US 2003220635 A1	27-11-2003
		AU 3741500 A	28-09-2000
		CA 2364098 A1	14-09-2000
		EP 1158919 A1	05-12-2001
		JP 2002537939 A	12-11-2002
		WO 0053113 A1	14-09-2000
WO 0053113 A	14-09-2000	AU 3741500 A	28-09-2000
		CA 2364098 A1	14-09-2000
		EP 1158919 A1	05-12-2001
		JP 2002537939 A	12-11-2002
		WO 0053113 A1	14-09-2000
		US 2002151887 A1	17-10-2002
		US 2002156471 A1	24-10-2002
		US 2003216728 A1	20-11-2003
		US 2004034346 A1	19-02-2004
		US 2003199866 A1	23-10-2003
		US 2004002704 A1	01-01-2004

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 0053113 A		US 2004000316 A1	01-01-2004
		US 2003212393 A1	13-11-2003
		US 2004030332 A1	12-02-2004
		US 2004002705 A1	01-01-2004
		US 2003220635 A1	27-11-2003
		US 6413255 B1	02-07-2002
US 2002120261 A1	29-08-2002	US 2002120260 A1	29-08-2002
		EP 1370187 A1	17-12-2003
		WO 02067797 A2	06-09-2002
US 6350276 B1	26-02-2002	US 2002062142 A1	23-05-2002
		US 5919219 A	06-07-1999
		US 6430446 B1	06-08-2002
		US 6241753 B1	05-06-2001
		AU 770936 B2	11-03-2004
		AU 5785300 A	31-01-2001
		CA 2376879 A1	04-01-2001
		EP 1196215 A1	17-04-2002
		JP 2003503118 T	28-01-2003
		WO 0100269 A1	04-01-2001
		US 2002049483 A1	25-04-2002
		US 2003216728 A1	20-11-2003
		US 2004034346 A1	19-02-2004
		US 2003199866 A1	23-10-2003
		US 2004002704 A1	01-01-2004
		US 2004000316 A1	01-01-2004
		US 2003212393 A1	13-11-2003
		US 2004030332 A1	12-02-2004
		US 2004002705 A1	01-01-2004
		US 2003220635 A1	27-11-2003
		AU 8903798 A	23-04-1999
		WO 9916502 A1	08-04-1999
		US 6405090 B1	11-06-2002
		AU 3824997 A	25-02-1998
		US 6438424 B1	20-08-2002
		WO 9805286 A1	12-02-1998
		AU 1527397 A	01-08-1997
		AU 5789396 A	21-11-1996
		EP 1407720 A1	14-04-2004
		EP 0957791 A1	24-11-1999
		JP 2001513654 T	04-09-2001
		JP 11504828 T	11-05-1999
		US 6377855 B1	23-04-2002
		US 6381497 B1	30-04-2002
		US 6381498 B1	30-04-2002
		WO 9634568 A1	07-11-1996
		WO 9724992 A1	17-07-1997
		US 6470216 B1	22-10-2002
		US 6461378 B1	08-10-2002
		US 6377854 B1	23-04-2002
WO 9743971 A	27-11-1997	US 5746224 A	05-05-1998
		US 5800429 A	01-09-1998
		US 5827277 A	27-10-1998
		US 5843077 A	01-12-1998
		US 5823197 A	20-10-1998
		AU 3119597 A	26-11-1997

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9743971 A		AU 3204097 A	09-12-1997
		WO 9743971 A2	27-11-1997
		WO 9741789 A1	13-11-1997
		US 2003144659 A1	31-07-2003
		US 2002091381 A1	11-07-2002
		US 6419673 B1	16-07-2002
		US 5743904 A	28-04-1998
		US 6077257 A	20-06-2000
		AU 2191697 A	09-12-1997
		WO 9743970 A1	27-11-1997